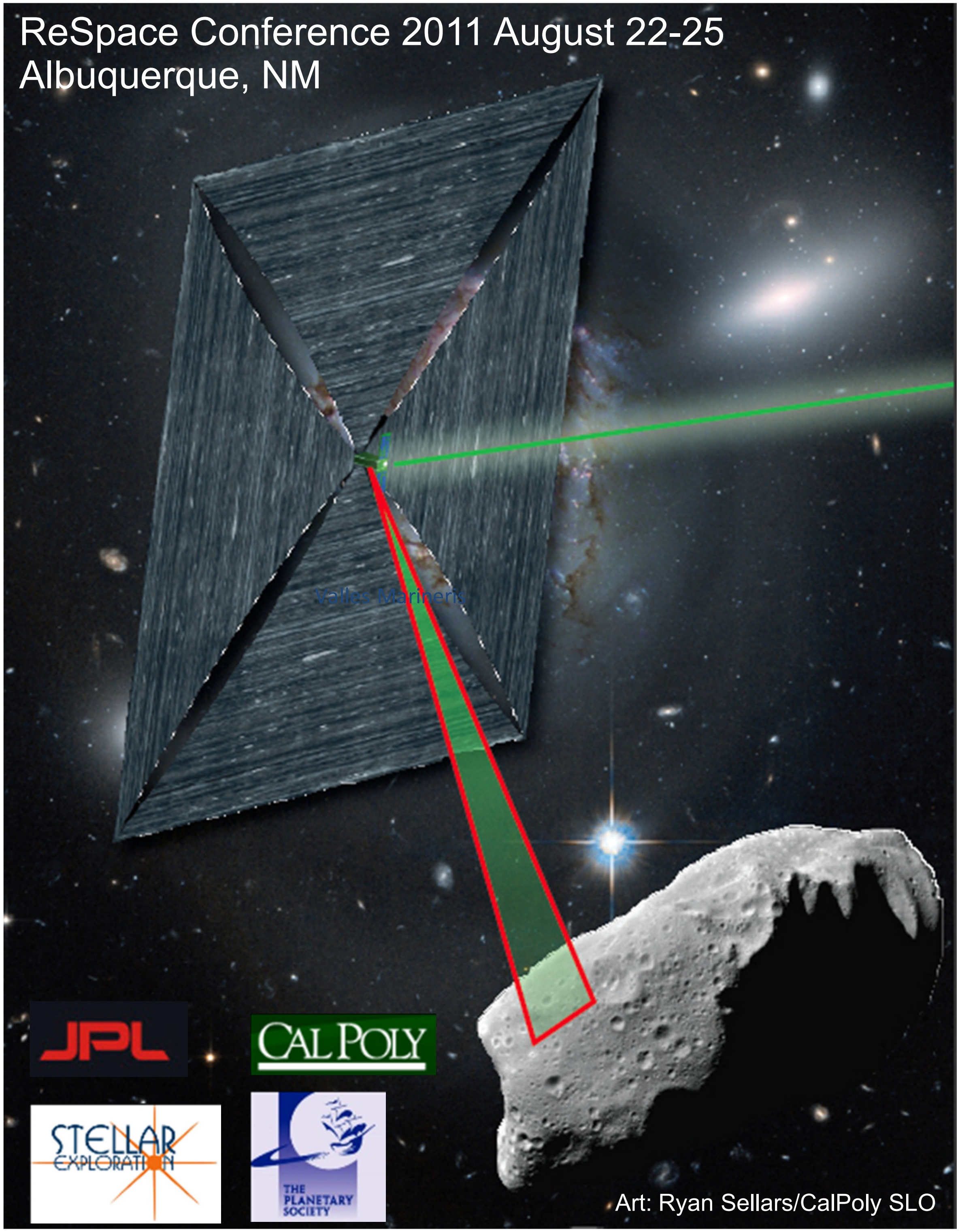

Art: Ryan Sellars/CalPoly SLO

Interplanetary CubeSats: Radiation Considerations for Low-Cost Electronics Beyond Low-Earth Orbit

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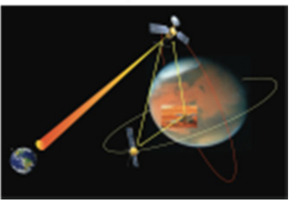
6 New Technologies → 1 New Architecture

CubeSat electronics and subsystems

- extended to operate in the interplanetary environment
- radiation and duration of operation

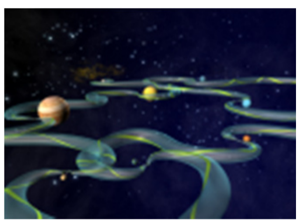


Optical telecommunications

- very small, low power uplink/downlink over 2 AU distances

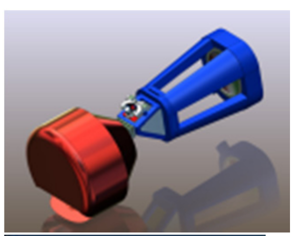
Solar sail propulsion

- rendezvous with multiple targets using no propellant



Navigation of the Interplanetary Superhighway

- multiple destinations over reasonable mission durations
- achievable ΔV



Small, highly capable instrumentation

- (miniature imaging spectrometer example)
- acquire high-quality scientific and exploration information

Onboard storage and processing

- maximum utility of uplink and downlink telecom capacity
- minimal operations staffing

?How does it fit?

6U Total (10 X 20 X 30 cm) ^

2U Miniature Imaging Spectrometer
visible/near-IR, $\Delta\lambda$= 10 nm
based on instruments currently being built at JPL

2U Solar sail: >6 X 6 m square → 5 m/sec/day @ 1 AU solar distance
based on Planetary Society/Stellar Exploration LightSail 1

1U Optical telecom flight terminal: 1 kbps @ 2 AU Earth-s/c distance
NIR transmitting to existing facility
based on JPL Laser Telecommunications development

1U Satellite housekeeping & instrument on-board processing
(C&DH, power, attitude determination & stabilization)
based on CalPoly CP7 and JPL/Univ of Michigan COVE

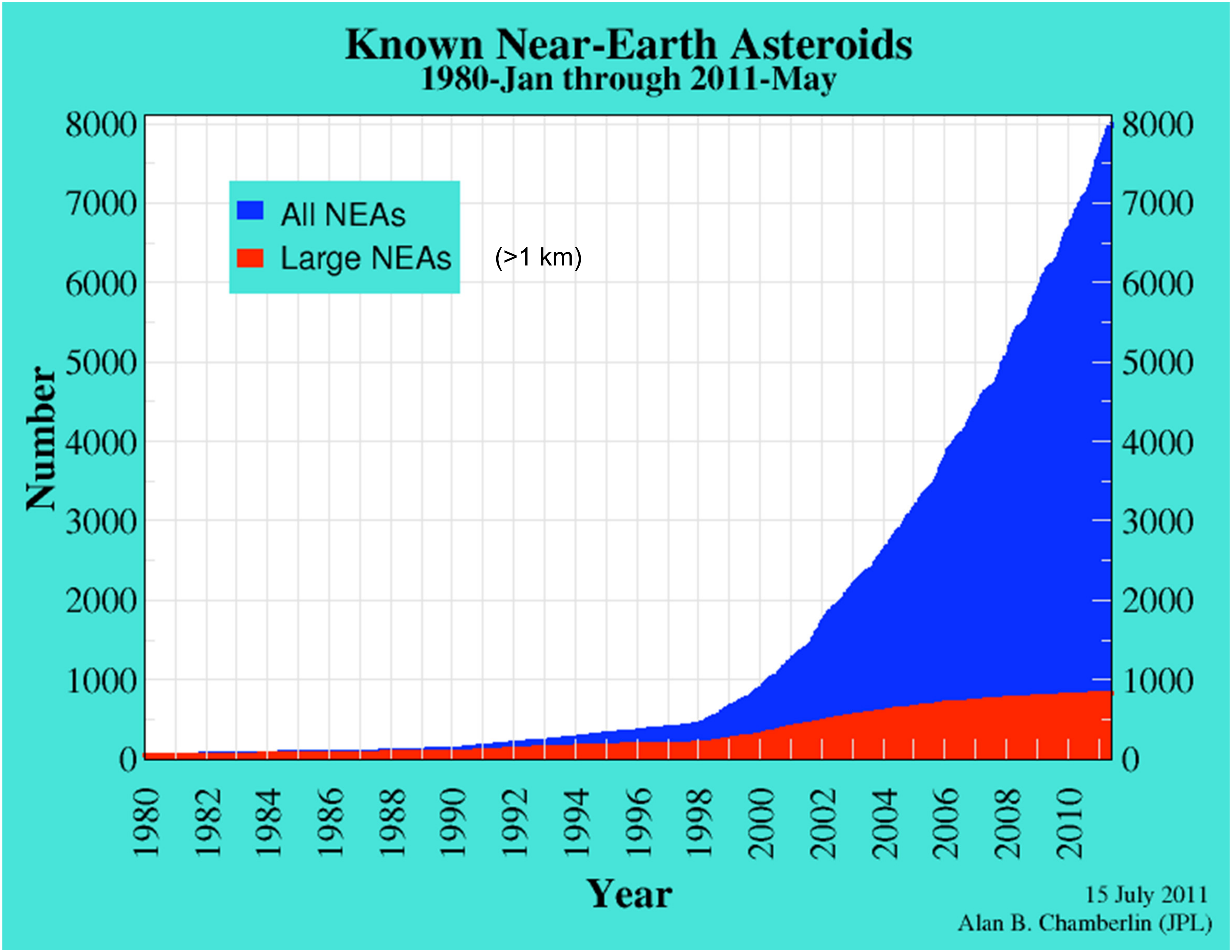
Example Science Mission Application:

Exploring a series of Near-Earth Asteroids

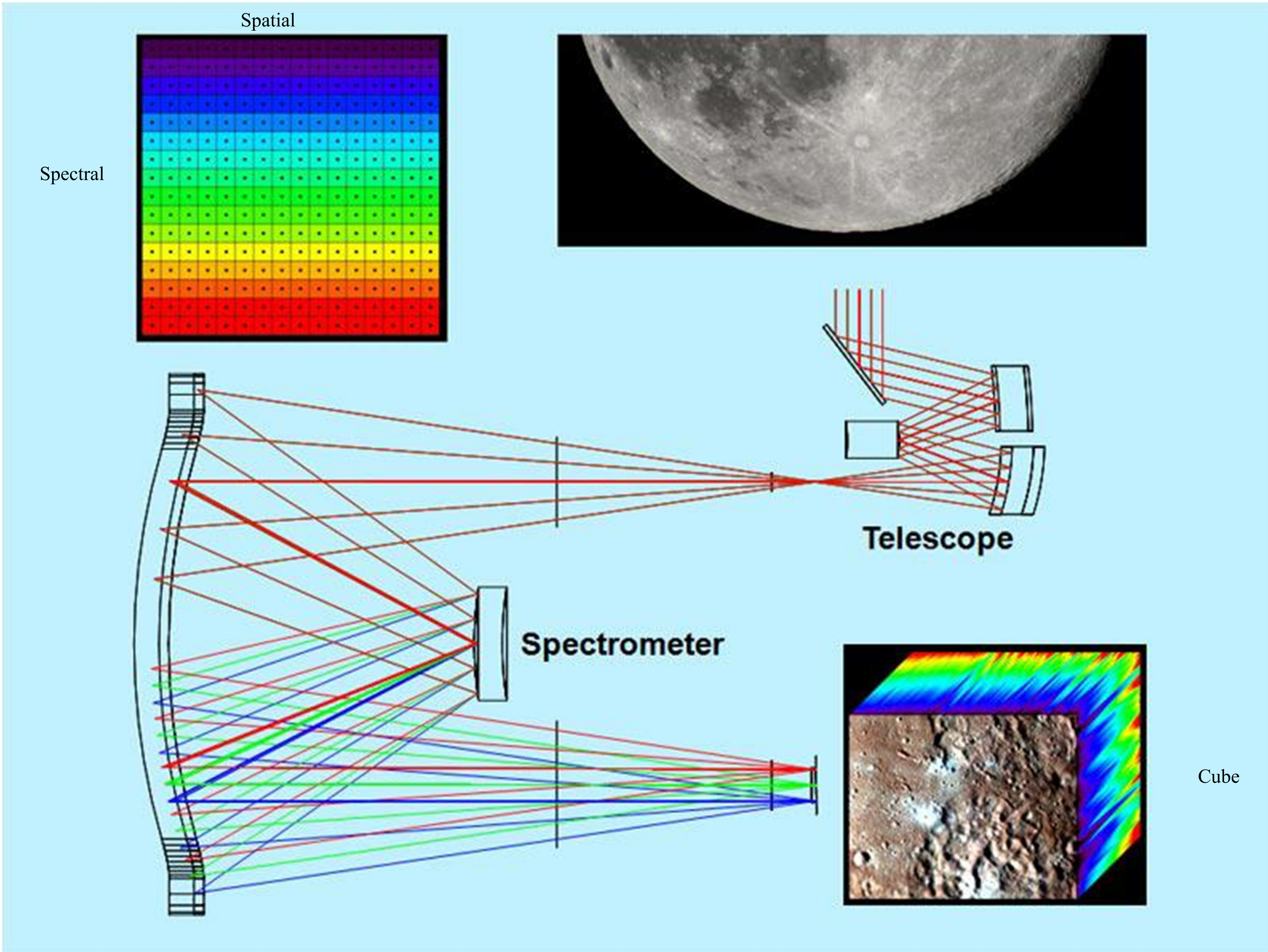
Other Candidate Science Missions

Space- and Helio-physics
Planetary Orbiters
High Solar Orbit Inclination

[insert your idea here…]



Known Near-Earth Asteroids
1980-Jan through 2011-May
All NEAs
Large NEAs
(>1 km)
Number
0
1000
2000
3000
4000
5000
6000
7000
8000
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year
15 July 2011
Alan B. Chamberlin (JPL)



Building an Image Cube: Moon Mineralogy Mapper Example

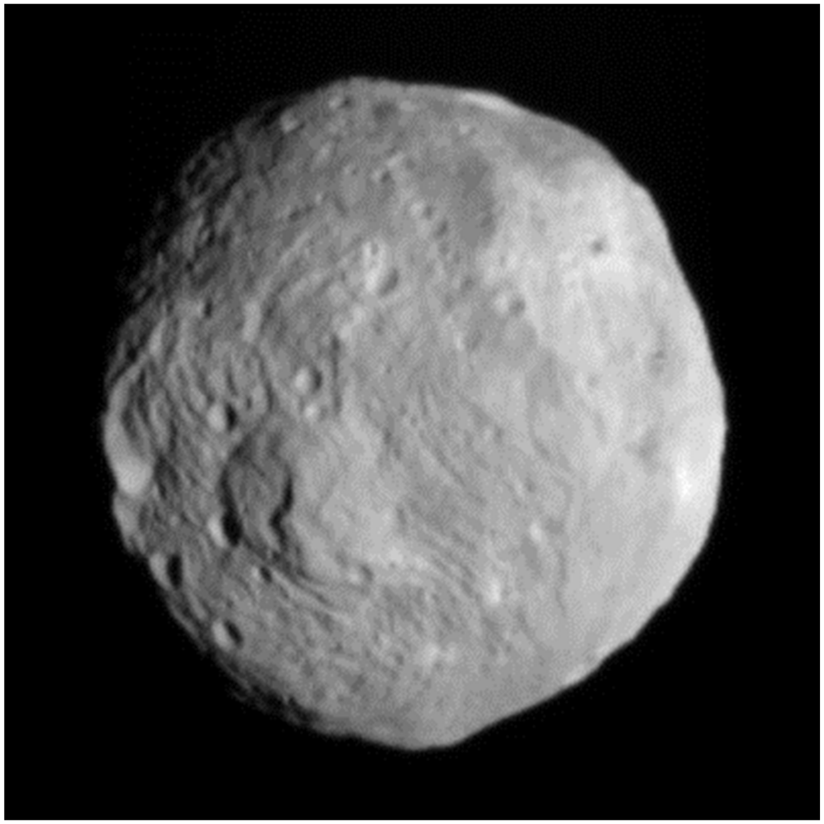
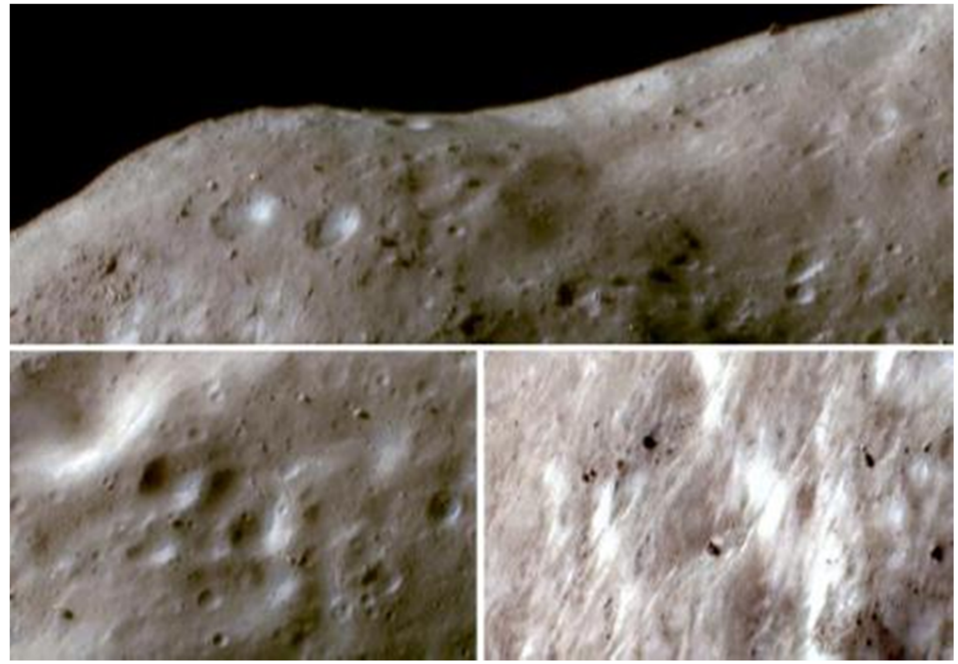
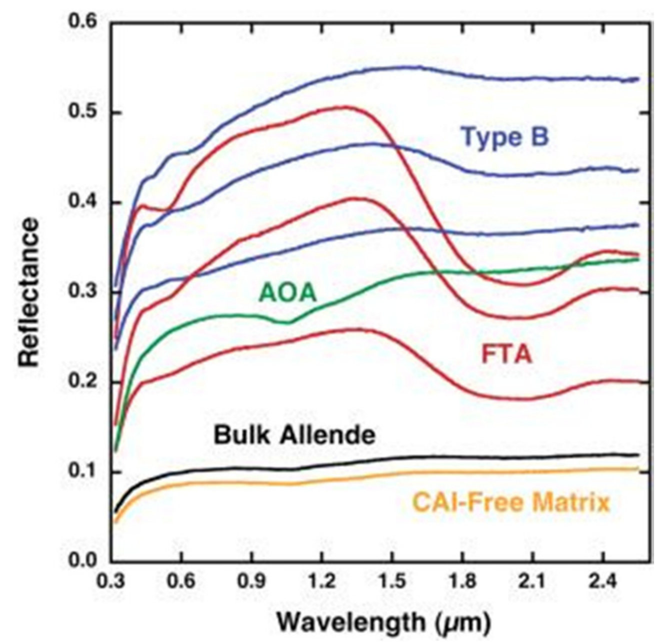


Image of the asteroid Vesta from the Dawn spacecraft.



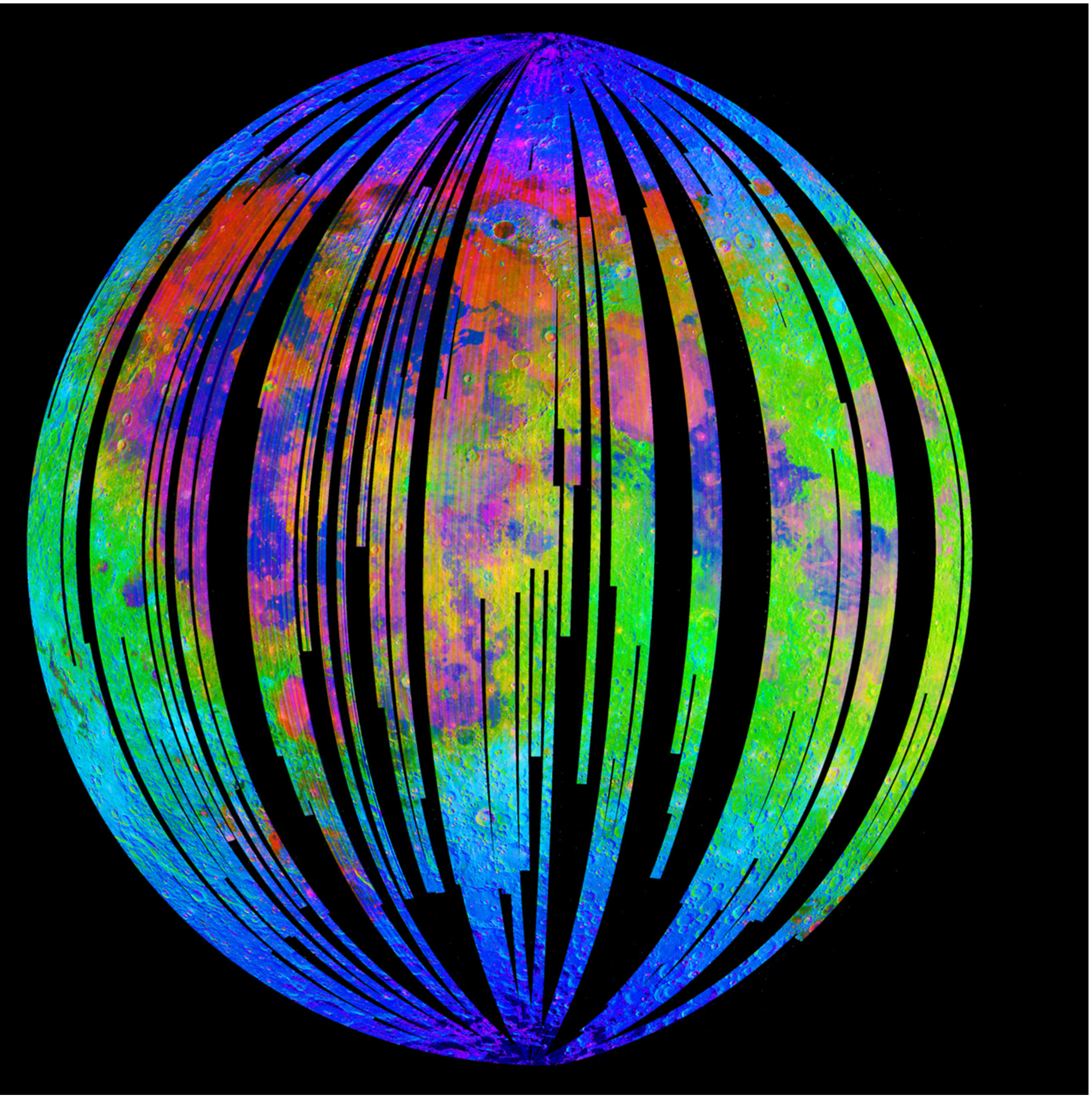
False color images of the asteroid Eros from the NEAR spacecraft.

True and False color imagse of the asteroid Gaspra from the Galileo spacecraft



Example infrared spectra of the materials in the meteorite Allende from Sunshine et al. 2008.

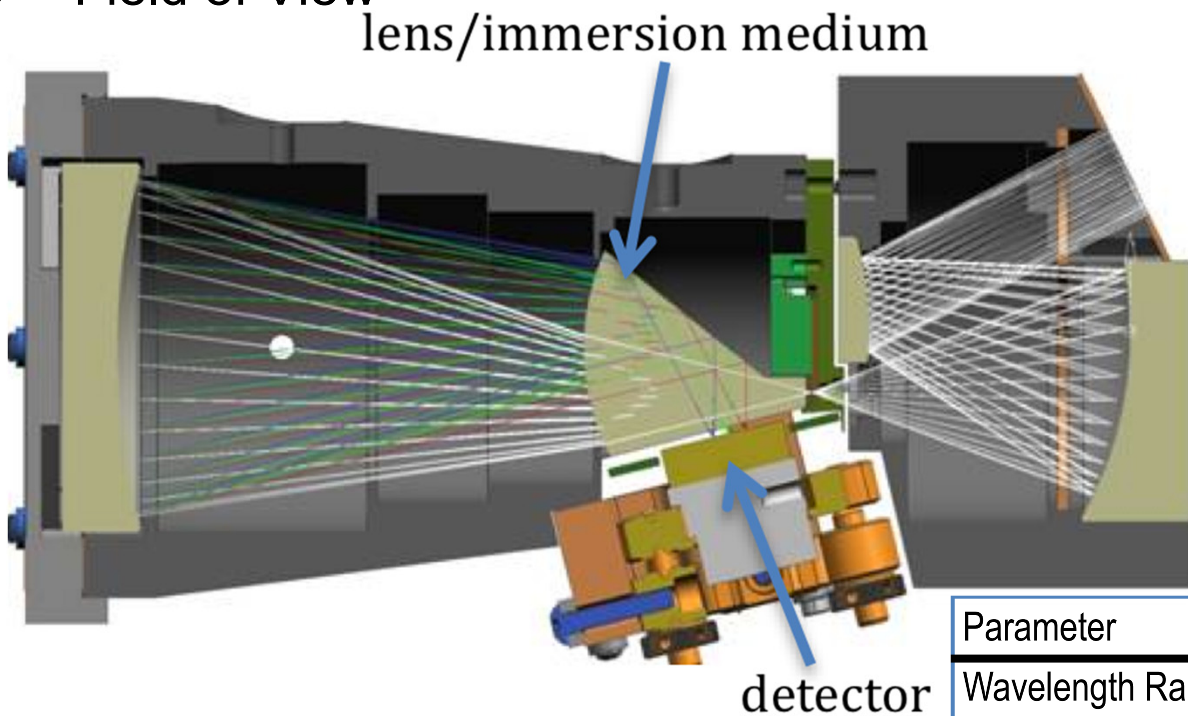
Mineral Map of the Moon



as in Carle Pieters/Brown Univ *et al.*
(Moon Mineralogy Mapper Team),
"Character and Spatial Distribution of OH/H_2O on the Surface of the Moon Seen by M^3 on Chandrayaan-1,"
Science 326, pp 568, 23 October 2009.

2U: Example Imaging Spectrometer

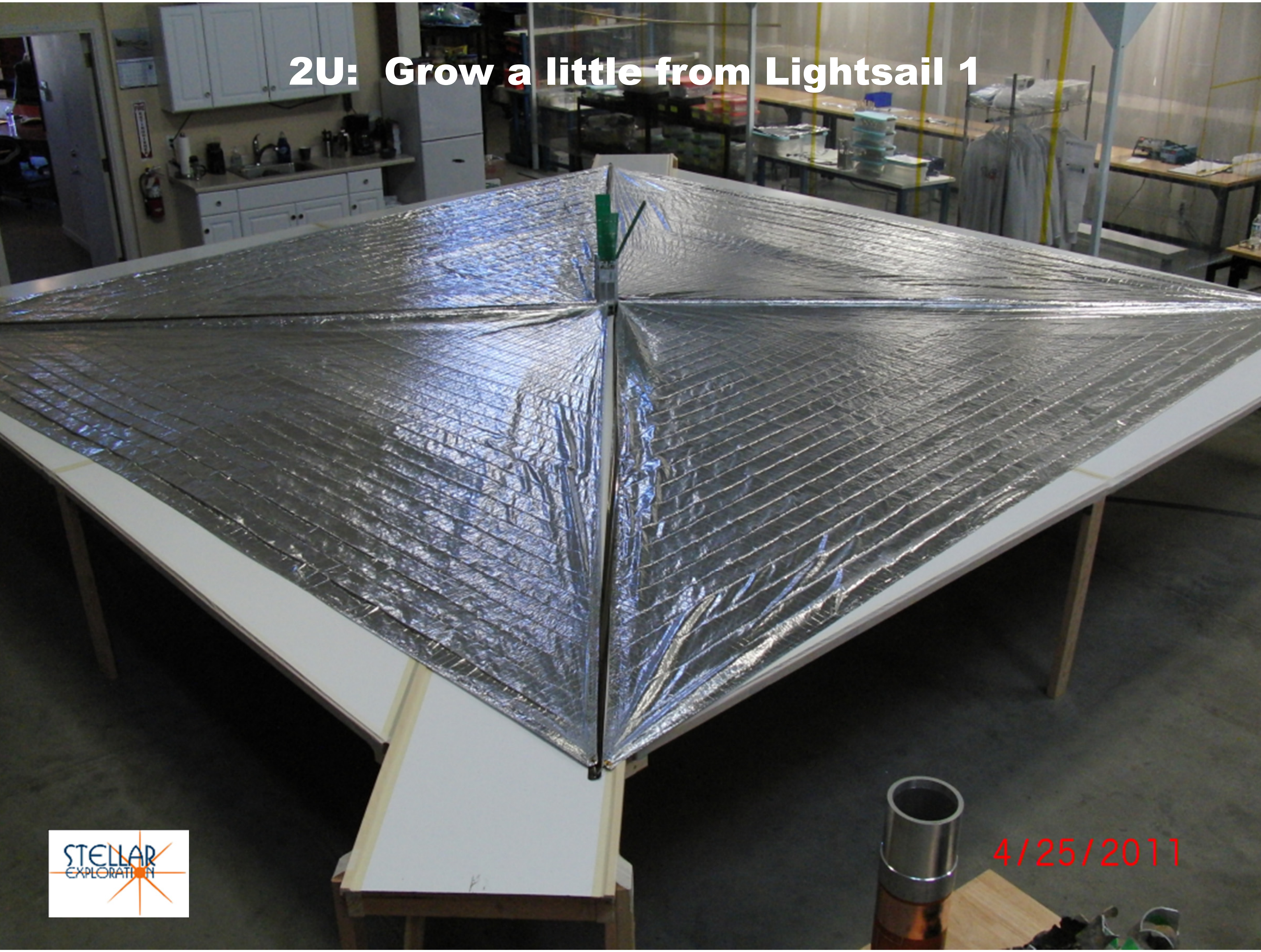
Representative Optical Layout:
Compact Dyson f/1.4 Imaging Spectrometer
33° Field of View



Specification for Interplanetary CubeSat

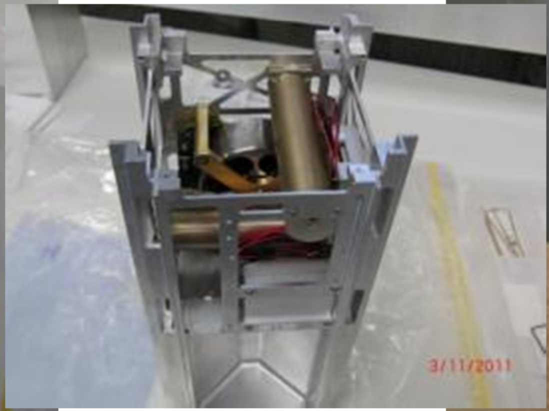
Parameter	Value
Wavelength Range	450- 1650 nm
Wavelength sampling	10 nm
Detector Type	Thinned InGaAs array
Pixel pitch	25 μm typ.
Angular Resolution	0.5 mrad
Field of View	14º
Detector Operating T	270 K
Response Uniformity	95%

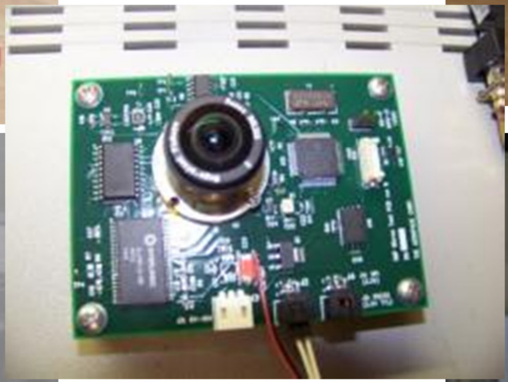
2U: Grow a little from Lightsail 1

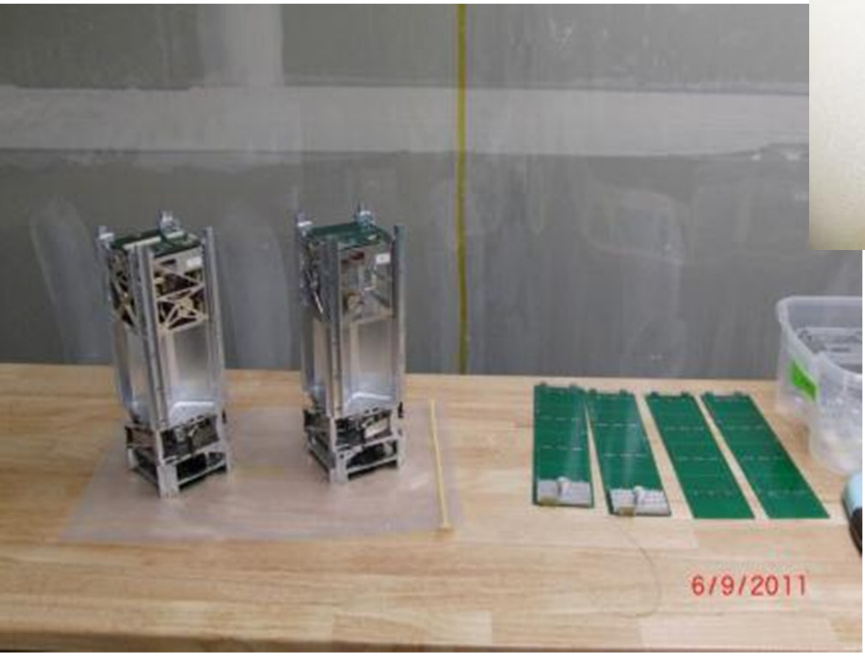


STELLAR EXPLORATION

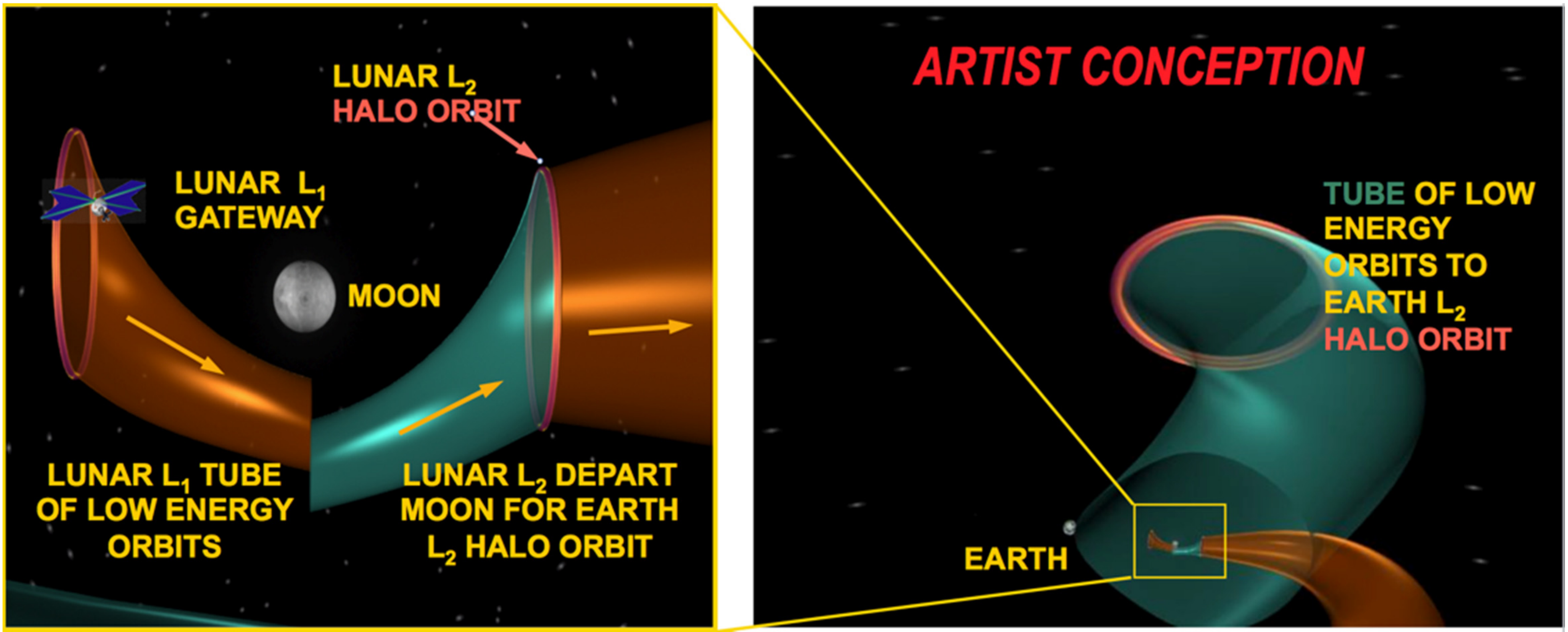
LightSail 1 Spacecraft



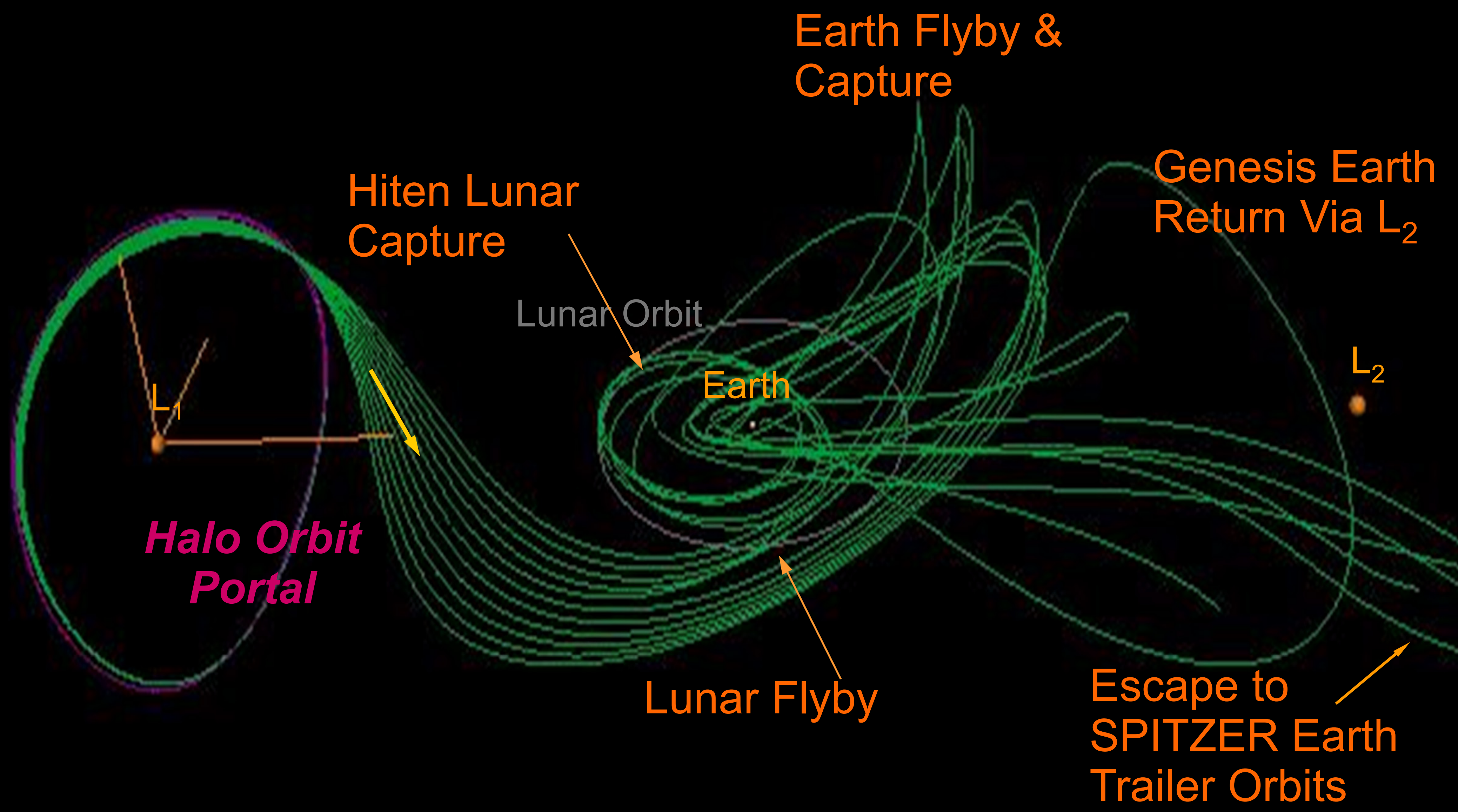




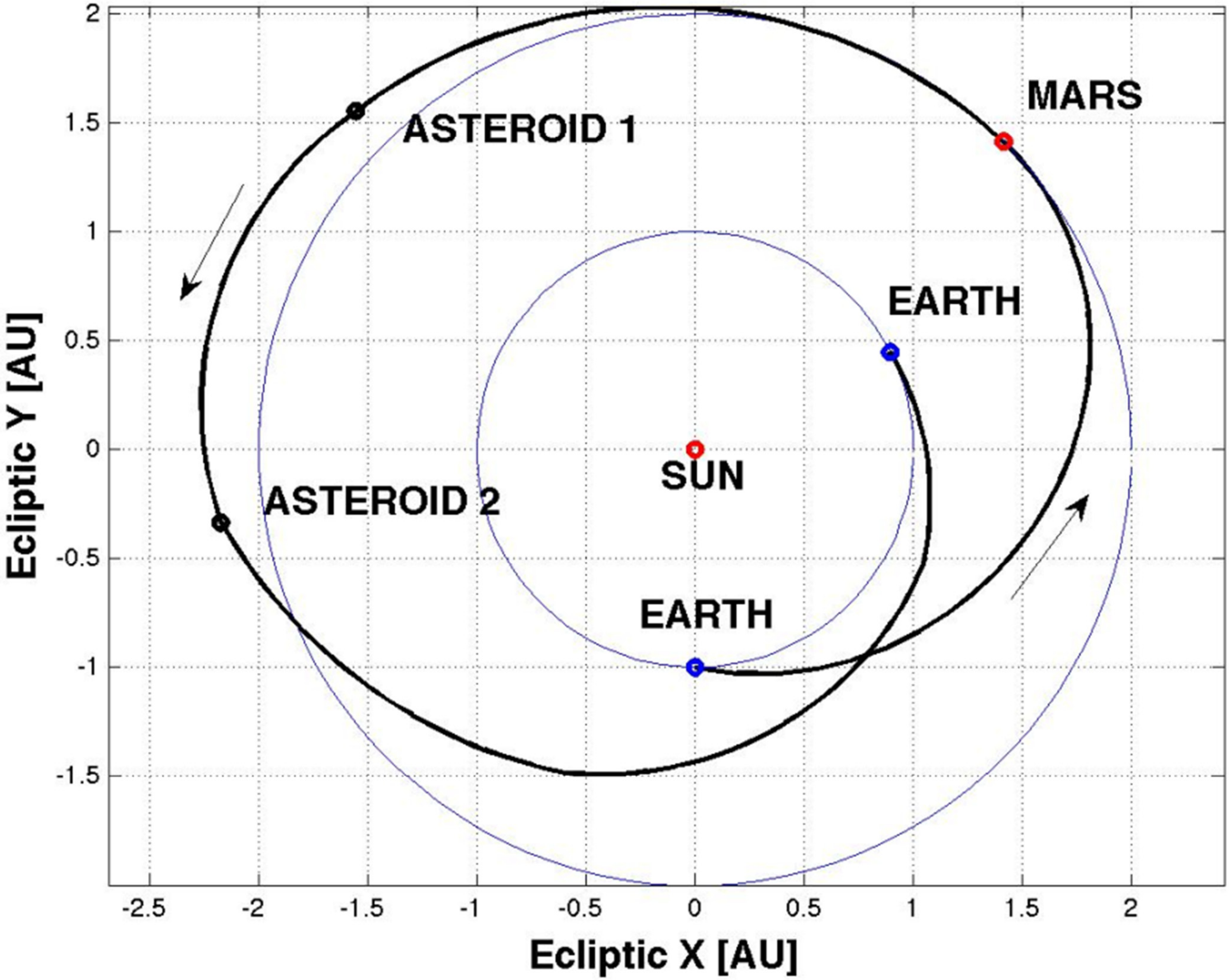
Interplanetary Superhighway



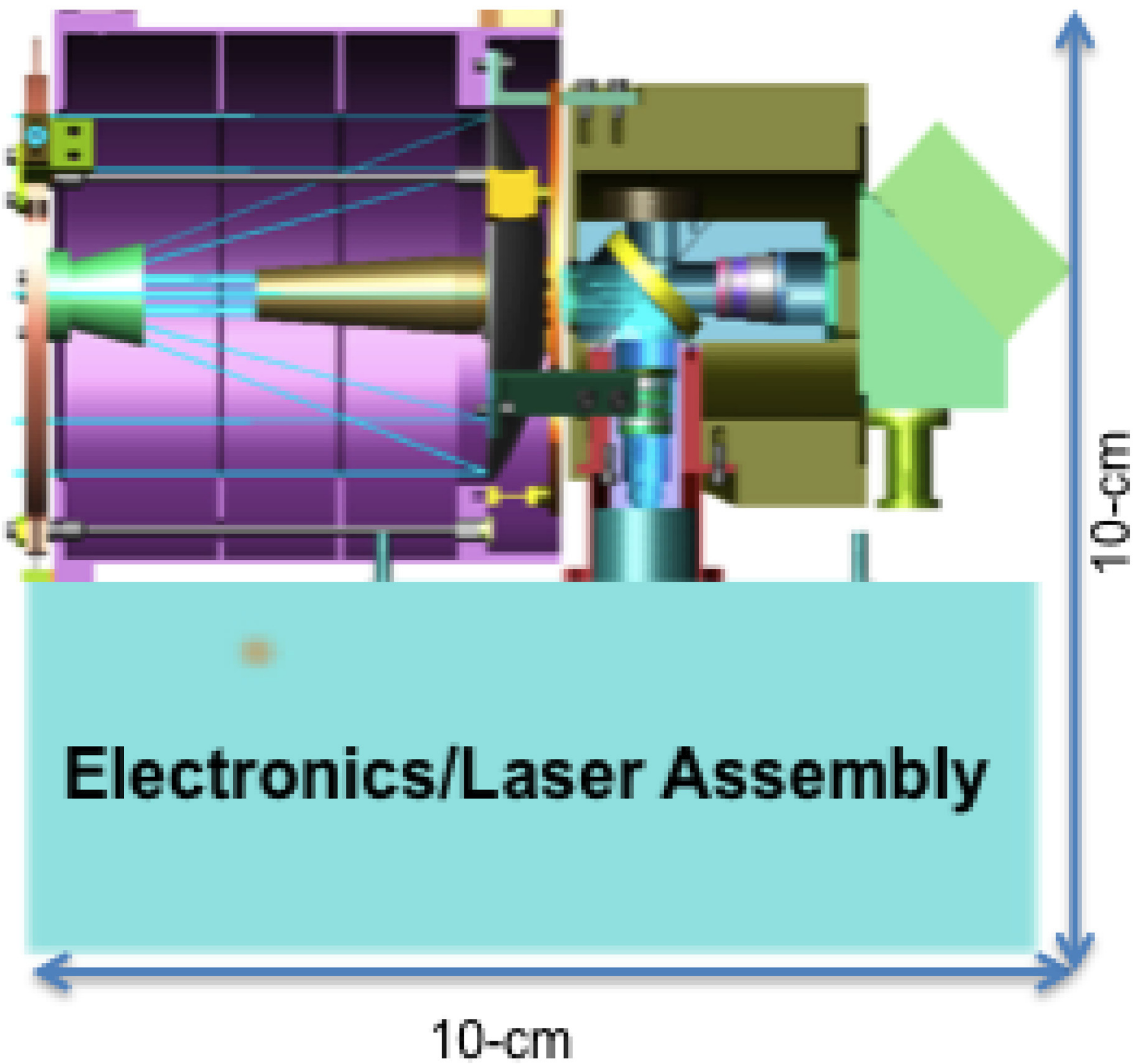
Genesis Return Trajectory's Unstable Manifold: Many Different Orbital Motions



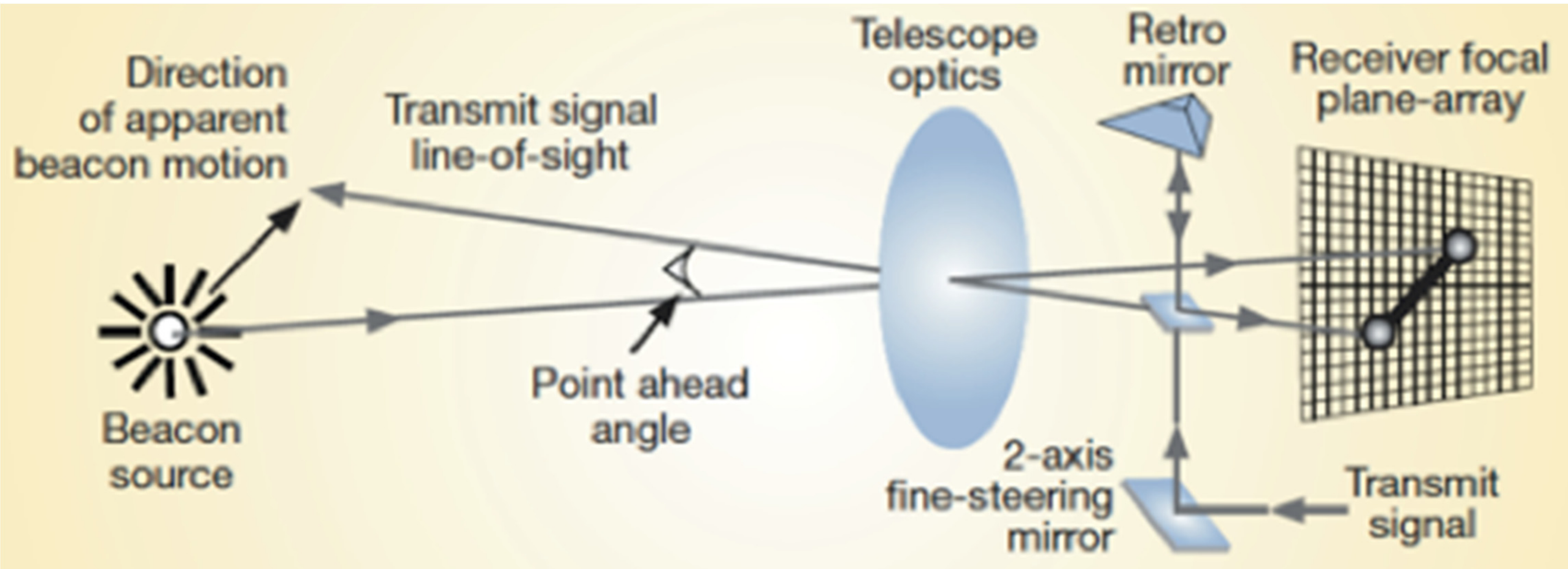
On the way to several asteroids...



1U: Laser Telecommunications Subsystem



Interplanetary Optical Communications Scheme



Lasercom Link Analysis Summary for 2 AU downlink

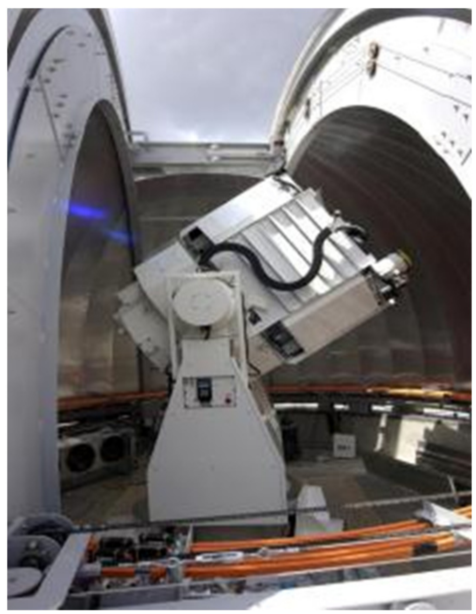
Assumptions/Input:

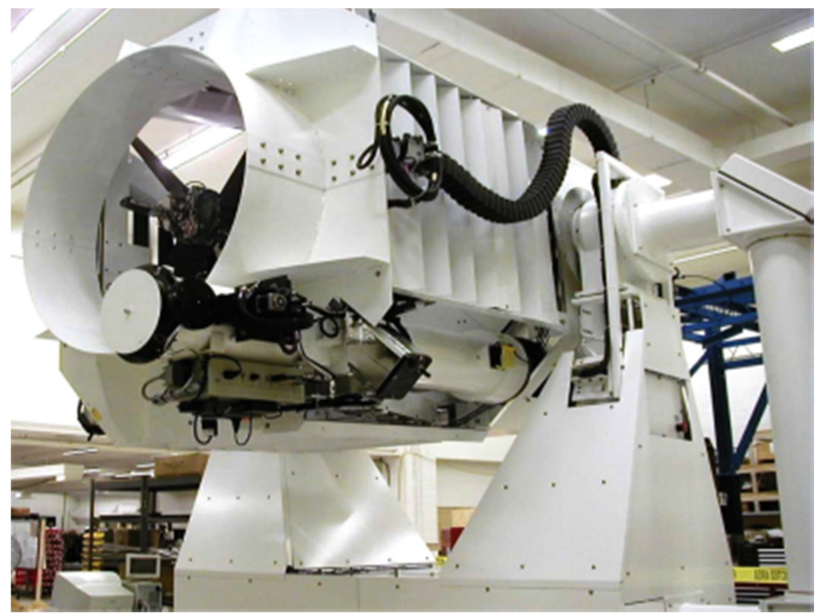
Average Laser Power:	0.5 W
Transmit Aperture:	6 cm
Pointing Accuracy:	10 μrad
Detection Efficiency:	50%
Effective Detector Diameter:	0.4 mm
Link Margin:	4 dB
Code:	SCPPM
Code Rate:	0.56
Sky Radiance:	9E-4 W/cm^2/sr/μm
Daytime SEP:	55°
Zenith Angle:	60°
r_0 (atmos. coherence length):	6 cm
Ground Telescope:	Hale/Palomar (5-m), or LBT (11.8m)

PPM Order	Slot Width (ns)	Laser Peak Power (W)	Mean PRF (kHz)	Throughput (kb/s)	Condition	Ground Telescope
256	263	160	11.042403	62.5	Night	LBT
256	263	160	11.042403	4	Night	Palomar
256	11601	160	11.042403	1.2	Day	LBT
256	11601	160	11.042403	0.2	Day	Palomar
128	789	80	10.38	56	Night	LBT
128	36926	80	10.38	0.7	Day	LBT
64	4905	40	2.6	44	Night	LBT
64	4905	40	2.6	0.4	Day	LBT

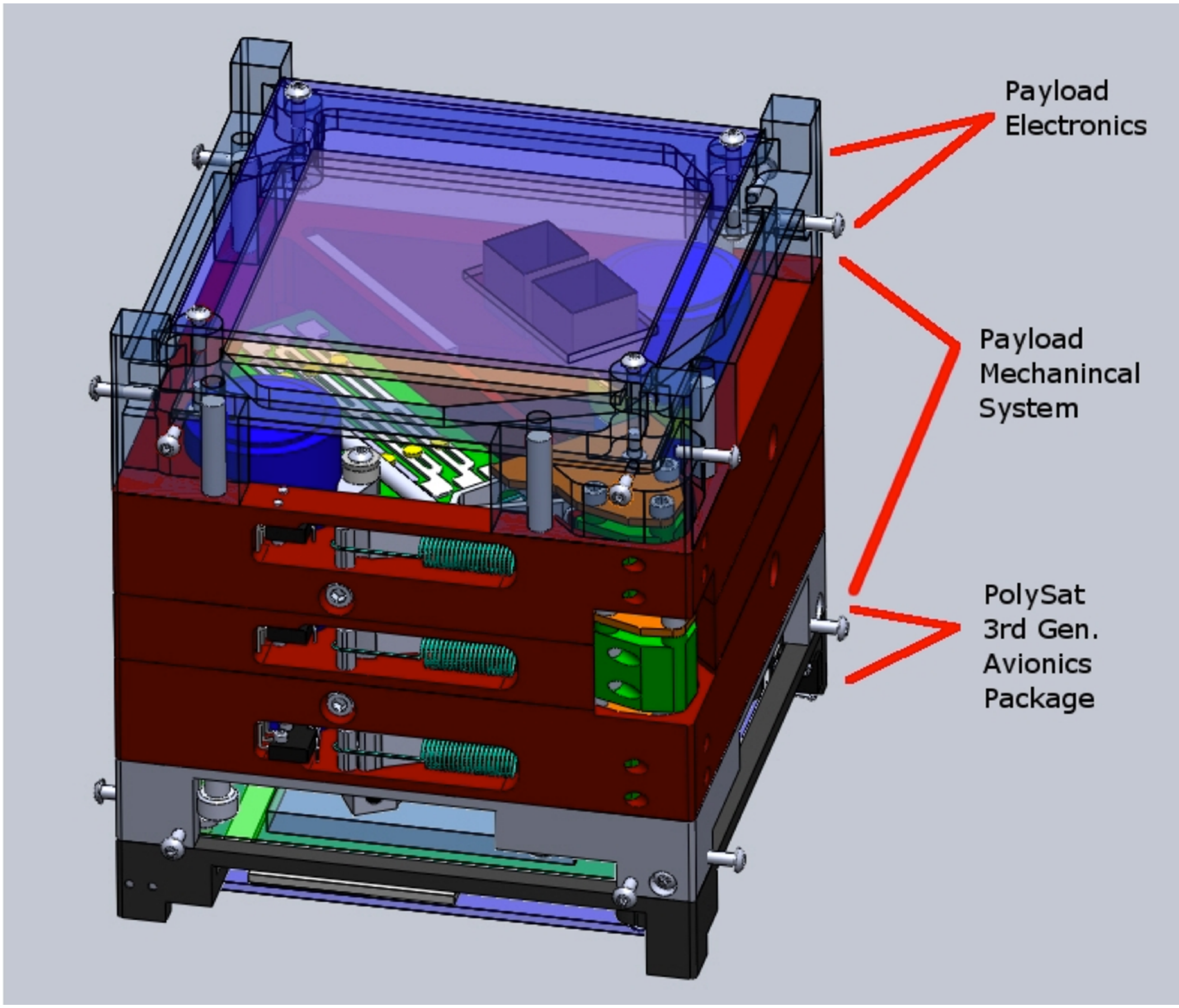
Optical Communications Telescope Laboratory (OCTL)

- 1-meter diameter telescope
- Lasercom-dedicated Daytime/Nighttime Telescope
- Capable of precision tracking LEO & GEO spacecraft
- Equipped with Adaptive Optics system
- Located at JPL's Table Mountain Facility (Wrightwood, CA)
- For deep-space comm, will be used to provide beacon/data





1U: evolve from Cal Poly CP7 Subsystem Electronics



...add COVE board evolved from UMich M-Cubed demo
...sail support components
...and spot shielding

Higher Radiation Resistance:

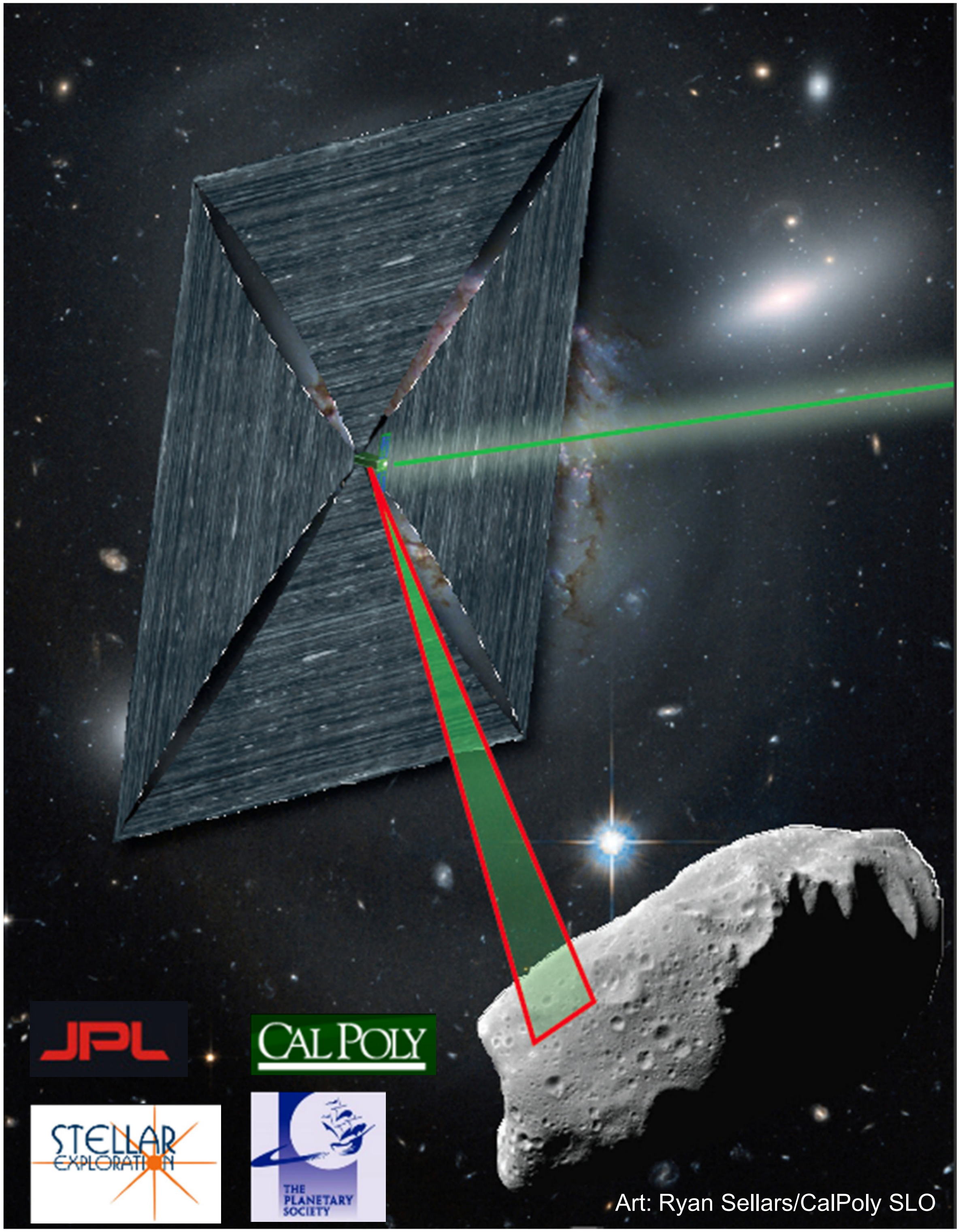
1. Xilinx V5QV SIRF

2. Phase Change Memory (PCM), 128 Mb

3. Magnetoresistive non-volative MRAM, 16 Mb x 2

Biggest Challenges

- Laser telecomm flight terminal to fit 1U
- Electronics reliability beyond low Earth orbit
- Extending sail performance
  - 5 m/sec/day ➔ >1 km/sec/yr (@ 1 AU)
  - Can we get to 20 m/sec/day?


JPL
CAL POLY
STELLAR EXPLORATION
THE PLANETARY SOCIETY
Art: Ryan Sellars/CalPoly SLO

THANK YOU!